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Physical Water Use and Water Sector Activity in Environmental Input-Output Analysis

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Abstract

This paper uses input-output accounting methods to identify the direct, indirect and induced physical demand for water. Previously the seminal work by Leontief (1970) has been employed to motivate a fuller account of issues related to sectors that generate and sectors that clean/treat polluting outputs (Allan et al 2007). The present paper extends this approach to deal with sectors that use a natural resource and the sector(s) that supply it. We focus on the case of water use and supply and a case study for the Welsh regional economy. The analysis shows how the proposed method, using both the quantity input-output model and the associated price dual, can be used to consider economy wide implications of the deviation between actual expenditure on the output of the water sector and actual physical water use. The price paid per physical amount of water appears to vary greatly amongst different uses. This may occur for various reasons. We argue that such analysis and information is essential for policy makers and regulators in understanding the demands on and supply of UK regional water resources, their role in supporting economic expansion, and can ultimately inform water sustainability objectives and strategies.

Key words:
Water resources; Full Leontief environmental model; Input-output; Multipliers; Wales

1. Introduction

Water policies and regulations across the EU (including the water framework directive WFD) (EU, 2000) provide legislation for planning and delivering better water environmental management (European Commission, 2011). DEFRA (2011) outlines the UK's obligations to deliver under the WFD and also provides wider context in terms of the uneven geographical distribution of water resources and different levels of stress on the resources. The UK's water-stressed regions tend to be more densely populated. Therefore, future water demands might involve unsustainable water abstraction levels and water stress in resource abundant regions in order to meet increased demand from more heavily populated areas. Water companies and regulators therefore face the challenge of comprehending the complex economic interactions determining water use and the sustainability of water supply (European Agency, 2015). In particular, there is a need to appreciate the economy-wide implications of future industry development and how water use in one industry connects to the embedded water use in supply chains.

This paper investigates the way in which input-output accounting methods can be used to improve our understanding of the direct, indirect and induced demand for a physical resource such as water. Conventional environmental input-output modelling attempts to capture emissions generation, or physical resource use, associated with economic activity. It does so by linking appropriate direct physical use/output coefficients to standard (economic) input-output multiplier results. Previously the seminal work by Leontief (1970) has been employed to motivate a fuller account of issues related to sectors that generate and sectors that clean/treat polluting outputs (Allan *et al*. 2007). Specifically, it considers the resource costs implied by internalising that level of externality that cannot be tolerated, and who bears them. The present paper extends this approach to deal with sectors that use a natural resource and the sector(s) that supply it, focusing on water and considering the resource costs of collecting, preparing and moving water to different types of user.

The paper uses the Welsh Input-Output Tables, together with data from the UK Environmental Accounts to construct three alternative water multiplier measures for Wales based around both physical and resource use methods. These produce quantitative results that differ, sometimes quite radically. The investigation of these differences is important for both policy and analysis. In this respect the analysis builds on, and extends, the earlier work of Weisz and Duchin (2006).

The remainder of the paper is structured as follows. Section 2 reviews early developments in environmental input-output modelling. Section 3 gives a step by step account of how insights from the Leontief (1970) general model can be applied to the demand for, and the supply of, a physical resource like water. Section 4 describes the data used in this application and the derivation of adjusted input-output rows that reflect the differences between payments actually made to the water sector and those implied by actual water use. Section 5 outlines the main findings of the analysis, focussing on the implications of these findings for the analysis of water resources within an input-output framework and for policymakers.

2. Water Resources and Input-Output Framework

The initial application of input-output analysis to the interaction between the economy and the environment dates back to the 1960s and 1970s. Early models focused on constructing what Miller and Blair (2009) refer to as “fully integrated models” (Daly, 1968; Isard, 1969). These studies attempted to model both the environmental and economic system in a manner consistent with the Material Balance Principle (MBP). In this approach, flows within and between the economy and the environment operate along the same lines as inter-regional trade in an inter-regional IO model. However, these all-encompassing economy-environment models were difficult to operationalise.

A second approach is based on the work of Leontief (1970) which discusses the construction of a “generalised input-output model” that links pollution generation directly to economic activity and associated cleaning behaviours (Miller and Blair, 2009). This approach augments the conventional (economic) input-output technical coefficients matrix with additional rows and columns to reflect pollution generation and abatement activities by economic sectors. The underlying principle of the Leontief (1970) model identifies pollution as a by-product of economic activities. This is particularly appropriate for pollutants whose cost is not internalised by the polluter. Once categorised as a negative externality, pollution can then be reduced through the operation of abatement sectors whose activity is at least partly endogenously determined.

More recent applications of environmental input-output models typically adopt an input-output approach that is influenced by both the Leontief generalised and limited economic-ecologic models (see Victor, 1972). They only consider the one-way link between the economy and the subsequent environmental or resource use implications but do not explicitly incorporate endogenous cleaning sectors and ecological inputs from the environment. In this paper we refer to this as the conventional environmental input-output approach. This method employs both the regular input-output Leontief inverse and a corresponding vector of direct physical pollutant (or resource use)/output ratios. It has been commonly applied for allocating responsibility for pollution generation embodied in trade flows, using multiregional, interregional and international input-output frameworks (Wiedmann, 2009; Wiedmann *et al.*, 2007). Other applications address natural/physical resource concerns (Lange, 1998)

This conventional environmental modelling approach has also been used to consider specific issues around water scarcity and trade (see, for example, Duarte and Yang, 2011). Dietzenbacher and Velázquez (2007) introduce the concept of ‘virtual water’ to the input-output literature in considering whether water scarce/abundant regions are likely to be net importers/exporters of water.[1] Other authors employ a multi-sectoral attribution to consider water allocation problems in and between regions facing acute water scarcity (Carter and Ireri, 1968; Feng *et al.* 2007; Guan and Hubacek, 2007; Seung *et al.* 1997). In this vein Velázquez (2006) developed an input-output model of industrial water consumption for Andalusia. This approach permits analysis of the direct and indirect consumption of scarce water resources allowing the potential for an economic and environmental policy oriented towards water saving.

Environmental input-output has also provided a framework for consumption accounting methods for dealing with water use and the estimation of national ‘water footprints’ (Cazcarro, *et al.*, 2010; Chapagain *et al.*, 2006; Hoekstra and Chapagain, 2007; Yu *et al.*, 2010). Using an illustrative approach, Zhang *et al.* (2010) show that Chinese water scarcity issues relate to a disconnect between the geographical distributions of water resources, economic development and other primary factors of production. This results in a separation of production and consumption of water-intensive products. These authors use a multi-regional input-output (MRIO) framework to estimate the nature of virtual water trade and consumption-based water footprints (see also Okadera *et al.*, 2015). Similarly, White *et al.*

[1] The concept of virtual water is the water use embedded, directly or indirectly, in the production of a good or service.

(2015) employed an integrated MRIO hydro-economic model to examine a consumption-based water footprint and the embedded water flows in inter-regional trade in China. They show that whilst there might be value in increasing imports of virtual water from water rich regions, care is needed because this could result in greater water stress in other water-scarce regions.

However, these developments neglect crucial aspects of the Leontief generalised model approach. These are the internalisation of the negative pollution impacts and the associated endogenous cleaning activities. There is limited work attempting to apply, discuss and explore the full Leontief (1970) environmental input-output model (Allan *et al.*, 2007; Leontief and Ford, 1972).

The Leontief generalised model approach can be usefully applied to water use. It identifies the economic resources employed in the collection, preparation and movement of water.[2] Two specific insights from the operation of the full environmental model prove to be particularly relevant in this case. First, the resources used in the water supply sector can act as an alternative index of water use. Second, differences between the water use multiplier values generated by the conventional environmental and the full Leontief generalised approach identify important issues for environmental input-output analysis in particular, but also for input-output analysis as a whole.

3. Method

Tracking water use through the conventional environmental input-output approach, proceeds in the following way. Sectorally disaggregated output in an economy with n sectors can be represented as (Miller and Blair, 2009):

$$q = [I - A]^{-1} f \quad (1)$$

In equation (1), q and f are respectively the (n x 1) output and final demand vectors, where the i^{th} element in each respectively is the output and final demand for the product or service generated by sector i. A is the (n x n) matrix of technical coefficients, where element, a_{ij},

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[2] The basic input-output water sector can be thought of as identifying that part of the combined human-environmental process that recycles waste water to usable water.

is the value input of sector i directly required to produce one unit of the value output of sector j.

The $\left[I-A\right]^{-1}$ matrix is the Leontief inverse. Each element, $\alpha_{i,j}$, gives the output in sector i directly or indirectly required to produce one unit of final demand in sector j. The sum of the elements of column j therefore gives the total value of output required, directly and indirectly, to meet one unit of final demand for the output of sector j. In the application of the conventional environmental input-output approach to water use, these value multipliers are transformed into physical water multipliers which measure the physical water required directly or indirectly to produce a unit of final demand expenditure in each sector. These are derived as the sum of the conventional column entries in the Leontief inverse, each weighted by the corresponding industry i's direct physical water coefficient. This generates a measure which is the direct and indirect use of physical water per unit value of final demand. This procedure is represented formally in equation (2).

$$m_1^p = w_1\left[I-A\right]^{-1} \quad (2)$$

In equation (2) m_1^p is a (1x n) row vector, where the i^{th} element is the i^{th} industry's physical water multiplier value and w_1 is a (1 x n) vector where the i^{th} term is the direct physical water use in sector i, $x_{k,i}$ divided by the total output of sector i, $q_{i,T}$, so that:

$$w_{1,i} = \frac{x_{k,i}}{q_{i,T}} \qquad \forall_i \quad (3)$$

Note that here, as elsewhere, the water sector is denoted as sector k.

Alternatively, the physical water multiplier, m_2^p, can be calculated using the Leontief generalised approach. In this case, rather than directly track the physical water use, the expenditure made on the water supply sector is used to indicate the resources used in cleaning and delivering water. To identify the direct and indirect water used in meeting a unit of final demand in sector j, we locate the j^{th} element on the water supply row (the k^{th} row) of the Leontief inverse and convert this value to physical units by dividing by the average price of water.

More formally, this is determined by pre-multiplying the Leontief Inverse by a (1 x n) row vector, w_2, where all elements are zero part from the j^{th}, which is the inverse of the average price of water, p_k^{-1}. This generates a (1 x n) row vector of physical water multiplier values, m_2^p, as:

$$m_2^p = w_2 \left[I - A \right]^{-1} \qquad (4)$$

The price of water is found by summing the total expenditure on the output of the water sector, across all intermediate and final demands taken from the input-output accounts, and dividing by the total water extracted for these uses.[3] Therefore:

$$p_k = \frac{\sum_{i=1\ldots n,f} q_{k,i}}{\sum_{i=1\ldots n,f} x_{k,i}} = \frac{q_{k,T}}{x_{k,T}} \qquad (5)$$

Where the f and T subscripts stand for final demand and total respectively. [4]

The multiplier values calculated using the standard environmental IO approach (equation 2) and the Leontief generalised approach (equation 4) are the same if one central assumptions of the value-denominated input-output analysis holds. This is that all uses of the output of a particular sector should face the same price for that good or service. In this specific case, this means that the two multiplier values will be equal if all users of water face the same price for water. If $m_1^p \neq m_2^p$, this is because the pattern of physical water use across sectors does not match the corresponding distribution of expenditure on the output of the water sector, as captured in the input-output accounts.

Discounting data reporting errors, there are two possible reasons why this might be the case. First, the technology for abstracting, treating and distributing water might differ between uses. As Duchin (2009) argues, water itself is a common pool resource that is not

[3] The way in which these physical figures are calculated is given in Section 4 and formalised in equations (11) to (14).

[4] An alternative way of calculating m_2^p is $m_2^p = w_3 \left[I - A \right]^{-1}$ where w_3 is a (1 x n) row vector where the ith element is $a_{k,i}/p_k$.

necessarily directly paid for. In the context of input-output accounts the water sector pays only for the resources needed to collect/abstract, treat and distribute water but not for the water itself. The differences in price per unit of physical water delivered could therefore reflect variations in the value of inputs needed to deliver that water to different uses.

An alternative explanation is that there is some form of price discrimination in the supply of water to different industries and elements of final demand. This perspective has been previously applied by Weisz and Duchin (2006) to consider the factors surrounding the differences between physical and monetary input output analysis in general. It has also been applied by Allan *et al.* (2007) in the specific application to the treatment of Scottish waste.

In the case of Allan *et al.*'s (2007) analysis of Scottish waste, the production sectors appear to pay only partially, and unsystematically, for waste treatment, so that, in effect, some sectors are charged more for waste disposal services than others. For the Welsh water use analysed in the present paper, all the transactions involve the public water supply and therefore in principle go through the market mechanism. Therefore in aggregate all the market resource costs are covered by firms paying for water as an intermediate input and consumers paying for domestic supply. However, if there is no difference in the resources needed to supply water to different users, then any difference between the two physical water multiplier values (m_1^p and m_2^p) is down to some form of price discrimination.

Whichever explanation applies, if these multiplier values differ, there are *prima facie* problems for input-output analysis. If the resources needed to deliver water varies across uses, and if these are large enough to cause significant variation in the multiplier values, then there should be greater disaggregation of the input-output table, particularly in this case the water sector. For example, a disaggregation between the provision of industrial and domestic water might be appropriate.[5] Only if the resources needed to deliver water are constant in composition across uses but vary in their ability to deliver the same quantity of water will the conventional environmental input-output multiplier, m_1^p, give the correct value (and the m_2^p value would give an inaccurate measure).

[5] In a similar situation, Allan 2007 disaggregate the electricity supply sector in the Scottish input-output table into generation and distribution and then consider different renewable technologies in the application of input-output analysis to energy issues.

Alternatively, if price differences solely reflect price discrimination, an appropriate adjustment can be made to correct the water multiplier calculations. This involves changing the entries in the water row of the A matrix of the initial input-output accounts to reflect the true/actual water use. The initial water row vector is therefore replaced by an implied water row vector derived from multiplying the physical water use per unit of value output divided by the average price of water.

Again, identifying the water input as the k^{th} row, the resulting vector of multiplier values, m_3^p , is given as:

$$m_3^p = w_2 \left[I - A^* \right]^{-1} \quad (6)$$

In equation (6), elements of the matrix A^* are given as the following:

$$\begin{aligned} &If\ i \neq k, \quad a_{i,j}^* = a_{i,j} \\ &If\ i = k, \quad a_{k,j}^* = \frac{x_{k,i} p_k}{q_{i,T}} = w_{1,i} p_k \end{aligned} \quad (7)$$

Under price discrimination, m_3^p is the correct water multiplier value.[6]

This procedure corrects the water multiplier value where price differences represent price discrimination. It is perhaps important to emphasise that this occurs through revising the entries in the conventional Leontief inverse. Imagine that there are price variations across the uses to which a particular product or service - the output of a specific sector - is put. In this case, a given expenditure is associated with a different physical output of the product, depending on the use for which that expenditure were made. This also applies to elements of final demand for water. For example, if exports receive a lower price than output sold to home consumers, then in increase in household consumption will be associated with a lower physical output, and a lower actual multiplier impact, than an increase in export expenditure.

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[6] An alternative way of dealing with the problem of pure price discrimination would be to construct the input-output table as a mixed table with the water sector specified in physical units (Duchin, 2009; Weitsz and Duchin, 2006). However, our approach mantains the accounting identities embedded in the value-denominated input-output accounts and facilitates the subsequent price adjustment calculation.

These problems occur whenever such price discrimination is present. Studying a relatively homogeneous sector, and focussing on the physical output of that sector, more easily reveals any price differences that exist. Whilst these challenges almost certainly apply in other sectors, and could be more prevalent with greater product differentiation, they are likely to be more difficult to detect.

Where the divergence between the relative value and quantity of water used is attributed to price discrimination, the input-output price model can determine the subsequent deviation in the prices of all commodities, and therefore the implicit price subsidies or penalties. The price model is the dual of the quantity model represented by equation (1). In the original set of input-output accounts the sector prices are calibrated to take unit values and have the following form:

$$i = \left[I - A^{T} \right]^{-1} v \qquad (8)$$

where i is a (n x1) vector of ones, $(I\text{-}A^{T})^{-1}$ is the Leontief price multiplier and v is the vector of unit value added figures in the initial period. Equation (9) gives the corresponding set of prices, p_3^p, where the original A matrix is replaced by the augmented A^* matrix.

$$p_3^p = \left[I - A^{*T} \right]^{-1} v \qquad (9)$$

This is the vector of prices that would hold if all sectors and final demand uses of water were charged at the same price. Adopting the price model allows the estimation of changes in relative prices across sectors that demand water services as inputs for production. Equation (10) calculates these changes Δp_3^p as the vector of percentage price variations:

$$\Delta p_3^p = \left[p_3^p - i \right] \times 100 \quad (10)$$

If the payment for the services of the water sector were always proportional to the physical amount of water purchased, then the multiplier values generated using equations (2) (4) and (6) would be the same, i.e. $m_1^p = m_2^p = m_3^p$ and each element of the Δp_3^p vector would be 0. However, this is not the case using the Welsh data. These results are discussed in some detail in Section 5.

4. Data and derivation of adjusted input-output row entries for actual and implied water use

This paper uses data relating to the public water supply sector in Wales, which is a devolved region of the United Kingdom. The input-output accounts are for 2007, the latest date for which the Welsh input-output table is available (Jones *et al*., 2010). These accounts identify the purchases and sales of 88 separately defined industrial sectors, one of which is water supply. Some aggregation of these sectors is required to make them consistent with the data that are available on the industrial use of water resources. Table A1 in the Appendix reveals the industrial aggregation used in this paper and how the 88 sectors in the Welsh input-output framework are mapped on to the 27 industries for which water consumption data are available.

Whilst the input-output data are Welsh specific, information on the physical water use has to be estimated by spatially disaggregating the English and Welsh Environmental Accounts. These provide information on industrial and household water use (public water supply) together with water companies' leakages in England and Wales for 2006-07.[7] From the outset it is important to say that this disaggregation is made primarily on the assumption that the intensity of water use across industries and for households do not differ between England and Wales. In so far as this is not true, the Welsh physical water use figures will contain inaccuracies.

The vector of Welsh industrial water use is calculated in the following way. Each element is determined by dividing the England and Wales water use figure in each industry in proportion to the corresponding industry's employment levels in the two regions. That is to say:

[7] Data in the UK Environmental Accounts for industrial water use in England and Wales were derived from sources including DEFRA, Environment Agency, WRAP and WRC and include household use, water company own use and system losses see www.ons.gov.uk/ons/dcp171778_267211.pdf

$$x_{k,i}^{W} = x_{k,i}^{E+W}\left[\frac{e_i^W}{e_i^{E+W}}\right] \qquad (11)$$

In equation (11), $x_{k,i}$ is the use of water in physical terms in industry i, (industry k is the water industry), e_i is employment in industry i, and the W and E superscripts apply to Wales and England respectively.

The Welsh household physical water use, $x_{k,h}^{W}$, is estimated based on the Welsh share of the England and Wales population (Pop^W/Pop^{E+W}). This is given as:

$$x_{k,h}^{W} = x_{k,h}^{E+W}\left[\frac{Pop^W}{Pop^{E+W}}\right] \qquad (12)$$

However, there is limited information on physical water supplied to all non-household final demand uses, $x_{k,nh}^{W}$. This is essentially export demand for Welsh water from England. The assumption is made that the physical share of non-household water output to the physical total output is equal to the value share of non-household final demand to the value of all Welsh water output, as given in the Welsh input-output tables. This corresponds to the assumption that all non-household final demand uses pay the industry average price for the water that they purchase, so that:[8]

$$x_{k,nh}^{W} = \left[\frac{q_{k,nh}^W}{q_{k,T}^W - q_{k,nh}^W}\right]\left[x_{k,h}^W + \sum_i x_{k,i}^W\right] = \frac{q_{k,nh}^W}{p_k} \qquad (13)$$

Total physical Welsh water generation, $x_{k,T}^{W}$, is the sum of the values calculated using equations (11), (12) and (13):

$$x_{k,T}^{W} = \sum_i x_{k,i}^W + x_{k,h}^W + x_{k,nh}^W \qquad (14)$$

[8] The price is determined in equation (5).

Using these procedures total Welsh water production in 2007 (public water supply) is estimated at 253 million cubic metres, of which households accounted for 158 million (63%) and 69 million cubic metres (27%) were supplied to Welsh industries as intermediate inputs.

Table 1 presents a condensed version of the 2007 Input-Output Tables for Wales, together with a number of additions. It shows the pattern of sales of the water sector, the physical use of water and the accounting adjustments required if expenditure on water is to match water use. Rows 1 to 6 give accounting data, measured in £ million, 2007 prices. Row 7 gives the physical water use, measured in millions of cubic metres, calculated as discussed in equations (11) to (14).

Rows 1 and 2 disaggregate the expenditures on domestic output made by industrial sectors and final demand. Row 1, labelled "Non-water sectors" are the payments made to the combined non-water sectors; that is, sectors 1-17 and 19-28 (see Table A1). The entries in row 2, 'Payments to water sector' give the payments entry for water services in the original input-output accounts. The total output of the water sector, at £697.82 million, is just less than 0.5% of the total Welsh output, which in 2007 is £140,916 million. Note that actual payments for water are dominated by final demand and particularly household demand which, at £512.42 million, makes up over 73% of the total. The expenditure on water as an intermediate input is highest for the 'Chemicals & Pharmaceuticals', 'Public Administration', 'Basic Metals' and 'Accommodation' sectors. Each of these Welsh sectors spent more than £10 million on water in 2007, the highest being Chemicals & Pharmaceuticals, at £13.29 million.

Row 3 reports the actual water use, measured in value terms. That is to say, it takes the physical water use figure from row 7 of Table 2 and multiplies this by the average price of water. The figure in row 3 is therefore the expenditure for water in its different uses that would be made if water had the same price in all uses. Note that rows 2 and 3 have the same row totals, but that the entries for individual uses differ, sometimes by a very large amount. To begin, the actual use of water as an intermediate input is measured as £190.01 million, over 66% higher than the actual payment for water as an intermediate. The household use indicates an equal, and opposite, position: household water payments are greater than the value of water use. For the adjusted water use by individual sectors, six sectors now have values greater than £10 million. These are, in descending order, ‘Agriculture, Forestry & Fishing’, ‘Food & Drink’, ‘Accommodation’, ‘Health’, ‘Other Business Services’ and ‘Chemicals & Pharmaceuticals’.

The figures in row 4, ‘Additional payment for water’ are the differences between the unadjusted (row 2) and adjusted (row 3) water payment entries. The row total is zero, so that overpayments are just balanced by underpayments. Where the entries are positive in this row, it implies an overpayment for water. This occurs for the household consumption but also for some industrial sectors, such as Coke & Refined Petroleum, ‘Chemicals & Pharmaceuticals’, ‘Basic Metals’, ‘Construction’, and ‘Public Administration’. These include some sectors (‘Chemicals and Basic Metals’) which are identified in previous analysis as high users of water per £ of Welsh GVA (Jones and Munday, 2011).[9] A negative row 4 entry shows that in the unadjusted system these sectors are net under payers. Of the 28 industrial sectors, 19 sectors are net under payers and with ‘Agriculture, Forestry & Fishing’, ‘Food & Drink’, ‘Education’ and ‘Health’ being responsible for over three quarters of this underpayment.

Rows 5 and 6 give the other primary inputs and total (unadjusted) value of inputs figures for each sector from the original Welsh table. The other primary inputs include payments for labour and other value added, together with imports (from both the rest of the UK and the rest of the World), taxes and subsidies. For each sector, the unadjusted value of inputs figure is also the value of output figure.

If the differences in the cost of water for different uses solely reflect price discrimination, the negative or positive row 4 entries indicate whether any given sector is directly subsidising water use in other parts of the economy or is being subsidised. As well as looking at the relative expenditure by individual production sectors, it is also important to identify the position relative to final demand uses. There are limitations here because for all non-household final demand sectors the assumption has been imposed, in the face of insufficient physical water use data, that these sectors fully pay for their water use, hence their zero value in row 4. However, the household sector’s additional payment entry, which is based on actual data, has a high positive value £75.76 million, suggesting that households

[9] This previous analysis also employed Welsh input-output tables for 2007, but a different set of water consumption data.

pay much more for water than their physical water use implies and are subsidising industrial water use, taken as a whole.

5. Application to Analysis of Industrial Water Use in Wales

In this section we use the Welsh data outlined in Section 4 to calculate the water multiplier values m_1^p, m_2^p and m_3^p given by equations (2), (4) and (6) in Section 3. We also use the equations (8), (9) and (10) to measure the price impacts from imposing a uniform pricing for Welsh water.

5.1 Physical water multiplier values

Table 2 presents the Type I and Type II values for the three physical water multipliers (m_1^p, m_2^p and m_3^p) outlined in Section 3. Also reported are the direct water coefficients required to calculate these multipliers. The first data column gives the physical water use coefficient ($x_{k,i}/q_{i,T}$), measured in thousands of cubic meters per £ million of output. These figures comprise the elements of the vector w_1. On this measure, the four most water intensive sectors, in descending order, are 'Agriculture, Forestry & Fishing', 'Mining & Quarrying', 'Food & Drink' and 'Accommodation'. All of these sectors have a water intensity value over 2 thousand cubic meters of water per £ million of output. The 'Agriculture, Forestry & Fishing' value at 8,790 cubic meters is particularly high.

The second data column reports the corresponding original direct water coefficient in the A matrix. These figures give the proportion of total costs in that sector going directly to the water sector. Using this metric, the top four most water intensive sectors are: 'Chemicals & Pharmaceuticals', 'Agriculture, Forestry & Fishing', 'Accommodation' and 'Non-Metallic Mineral'. It is clear that ordering the sectors by the share of costs which go to intermediate water expenditure differs from ordering by the physical water-use intensity.

The third column gives the adjusted expenditure coefficients calculated by multiplying the physical coefficients in column 1 by the price of water and dividing by a thousand. These are the water row coefficients used in the A^* matrix incorporated in the Leontief inverse employed in the calculation of m_3^p. The ordering of water intensities is exactly the same as in column 1 but a comparison of columns 2 and 3 indicates the extent to which the two water intensity measures differ.

For most industries, the adjusted coefficient is greater than the coefficient in the original input-output table. This is a corollary of the fact that the input-output accounts measure industrial expenditure to be less, and household expenditure to be more, water intensive than the physical figures. The four sectors with the biggest difference in absolute terms between the adjusted and initial water coefficients are, again in decreasing order: 'Agriculture, Forestry & Fishing', 'Mining & Quarrying', 'Food & Drink' and 'Furniture'. In all these sectors, the actual payment is lower than the amount of water used, valued at a constant price. These adjustments are valued at 2.03%, 0.7%, 0.4% and 0.2% respectively of the total costs for these sectors. The four sectors which have the biggest negative difference between their adjusted and actual water payment are 'Chemicals & Pharmaceuticals', Coke & Refined Petroleum, 'Basic Metals' and 'Public Administration'. This indicates that these sectors are paying more for their water use than would be expected from the physical figures. However, these values are much smaller, at 0.09%, 0.08%, 0.06% and 0.05% of total costs respectively.

The figures in columns 4 and 5 give the physical water Type I and Type II multiplier values using the conventional environmental input-output approach, m_1^p, as given in equation (2). They are measured in thousand cubic meters for each £million of final demand expenditure. The Type I multipliers include only direct and indirect effects. That is to say, in measuring Type I multipliers household consumption is held constant and only endogenous intermediate water demands are included as elements of the supply chain. It is Type I multipliers that are typically used for footprint analysis. Type II multipliers also incorporate the induced water consumption of direct workers, and also those workers attributed to the sectors extended supply chain. This would be the most appropriate multiplier value for increases in activity which were expected to be accompanied by increases in population.

The conventional Type I physical water multiplier value presented in column 4 must be higher than the corresponding direct water coefficient shown in column 1, because it incorporates both the direct water input and the embedded water in the other intermediate inputs. For example, in 'Agriculture, Forestry & Fishing', the direct water use is 8,790 cubic meters per £1 million final demand whereas the conventional Type I value is 9,790 cubic meters. Typically, the difference is relatively small but in some cases the proportionate differences can be large. The ‘Food & Drink’ sector has a direct water coefficient of 2,320 cubic meters but a Type I multiplier value 60% higher at 3,790 cubic meters per £ million of final demand.

The conventional physical Type II water multiplier values are higher still, as they incorporate additional induced household water use. The Type II measure used endogenises all the household water use, which is more than double intermediate water use. Therefore, the Type II physical water multiplier is significantly higher than the Type I value for most sectors. Although the ‘Agriculture, Forestry & Fishing’ sector maintains its position as the most water intensive on this measure, other, more labour intensive, sectors begin to play a more prominent role. ‘Education’ moves from 1,110 cubic meters on the Type I multiplier to 8,230 cubic meters for the Type II and takes second place on that measure. ‘Accommodation’ shows a similarly large gain moving from the Type I to Type II multiplier measure and at 6,740 cubic meters per £1 million final demand is the third most water intensive sector.

The Type I and Type II physical water multiplier values calculated on the basis of water sector payments are shown in columns 6 and 7. Note first the low value for the Type I multiplier values. For 20 industries the Type I m_2^p multiplier value is lower than the corresponding m_1^p figure. The Type I m_2^p multiplier value is never greater than 2,000 cubic meters per £1million and in only five sectors is it greater than 1,000 cubic meters per £1 million. ‘Chemicals & Pharmaceuticals’ has the largest value, at 1,830 cubic meters, followed by ‘Agriculture, Forestry & Fishing’, ‘Accommodation’, ‘Food & Drink’ sectors. The relative low measure stems from the lower expenditure on water as an intermediate input than would be expected from the physical water use.

The Type II values incorporate household water use which is overvalued in the expenditure (as against physical) figures. This means that there is no overall bias in the Type II m_2^p value but there are big differences in the Type II m_1^p and m_2^p values for some individual sectors. Examples are ‘Agriculture Forestry & Fishing’, ‘Mining & Quarrying’, ‘Food & Drink’ and ‘Wood’.

The m_3^p multiplier adjusts the Leontief inverse so that the technical water expenditure coefficients match the physical intermediate and final demand water use values. If the adjusted A matrix is used, the conventional and the extended Leontief multiplier values into line, so that $w_1\left[1-A^*\right]^{-1} = w_2\left[1-A^*\right]^{-1}$. This is the appropriate procedure if the mismatch between the physical and expenditure water use data is solely due to price discrimination amongst water uses. In this case it is clear that the m_3^p values are much closer to those for m_1^p than to those for m_2^p. This suggests that calculating the physical water multipliers by just tracking the value of output of water sector will give potentially very inaccurate multiplier values for some individual sectors. On the other hand, the conventional environmental approach, which augments the value Leontief inverse with direct physical water/output ratios generates multiplier estimates which, whist theoretically incorrect, are extremely close to the m_3^p values. However, this almost certainly reflects the small scale of the water sector in the Welsh economy. Adjusting the coefficients for a large sector should have bigger impacts on the calculated inverse values.

5.2 Price multipliers

If the variation across uses in the price paid per unit of delivered physical water is the result of pure price discrimination, then the impact on commodity prices of adjusting the water payments for the actual direct water use can be calculated using equations (8), (9) and (10). The deviations from the original prices are given in Table 3. These figures show whether sectors at present bear the full resource cost (or not) of water use through direct and/or knock on impacts on the price of their output. Column 1 reports the impacts on the prices of sectoral output using the Type I price multiplier values and the adjusted system. In this case wage payments are taken as an element of the value added vector, v, and do not adjust to variations in the sector prices; the nominal wage is held constant. The percentage change in prices in column 2 identify the corresponding results using Type II multipliers. Essentially this holds the real wage constant and adjusts the nominal wage to changes in sector prices. An important issue here is that the price consumers pay for water is above the average price so that an adjustment to uniform pricing will have a direct impact on the nominal wage.

In the Type I case there are 7 sectors where the price of output would be lower if a uniform price is charged for water across all uses. The largest negative adjustments are for the 'Construction', 'Coke & Refined Petroleum' and 'Chemicals & Pharmaceuticals' sectors. However, these impacts are small. These sectors all suffer a cost disadvantage of less than 0.1% stemming from the existing water price differentials. In 21 sectors the adjustment increases the Type I price multiplier values. In some cases, the impact is particularly high, with the 'Agriculture, Forestry & Fishing' price increasing by 2.24% and prices in the 'Mining & Quarrying', and 'Food & Drink' sectors rising by 0.80% and 0.74% respectively.

In calculating the Type II adjusted prices, two changes to the Type I method are made. First wage income is removed from the vector of sectoral value added, so that all elements in the value added vector are reduced. Second, the A matrix is augmented to incorporate the wage and household expenditure. The net impact is to reduce the adjusted price in all sectors as against the Type I value. That is to say, if with the Type I multiplier the price adjustment was negative, it is even more negative with the Type II calculation. On the other hand, if the Type I price change is positive, the Type II value will be smaller, or even negative.

The biggest difference occurs for Education. Row 4 in Table 3 shows that Education is a net under-payer for water. This is reflected in the higher Type I price multiplier in the first column of Table 7. However, Education is a labour/wage intensive sector. This means that in the Type II case it is impacted by the effect of households over-paying for water as an "input" to provision of labour services. In the adjusted system, on the other hand, where households only pay the unit cost for the water they actually use, this puts downward pressure on the cost of labour and on the price multipliers of labour-using sectors.

6. Conclusions

This paper explores alternative input-output approaches to generating physical multiplier values using Welsh water data. In particular, it compares the results from using the conventional physical environmental input-output model with an approach based upon an earlier generalised Leontief (1970) method, both with and without adjustments to the A matrix. Essentially the generalised Leontief method uses the demand for the output of the industry involved in the collection, preparation and movement of water as an index of physical water use. The motivation for using this alternative approach came from the importance attached in Leontief (1970) for cleaning sectors. However, in many other cases the physical use of environmental goods, such as rare metals, could be tracked by the expenditures on the industries supplying such goods.

In the case of Welsh water, the generalised Leontief model works very badly. This is because the price paid per physical amount of water appears to vary greatly amongst different uses. In general, the data suggest water used for household consumption is charged at a higher price than for intermediate industrial demand. There is also a wide price variation across different industries. Only if physical water-use data are employed to adjust the input-output A matrix does the generalised Leontief model work satisfactorily. In principle this is problematic for input-output analysis in general. However, the small scale of the Welsh water sector means that in actual fact, the conventional environmental input-output multipliers appear to be quite accurate.

In terms of implications for policy, they key issue is that accurate physical water multiplier values are required in order to calculate the impact of industrial development strategies on the demand for water and therefore the sustainability of growth. The major policy implication of this work for Wales is that water expenditure information reported in the core economic input-output accounts is inadequate for producing accurate physical water multiplier values. This implies that the tables must be augmented with direct physical water coefficients. However, physical data on resource use and physical data (often referred to as environmental satellite accounts) are commonly not available, particularly at a regional level. Section 4 has explained that Welsh specific physical water coefficients are unavailable so that averages across a wider ‘England and Wales’ region have had to be applied.

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Table 1. The conventional and full Leontief environmental Wales industry-by-industry (28x28) IO table for 2007 (£million, condensed)

	Agriculture, Forestry & Fishing	Mining & Quarry	Food & Drink	Clothing & Textiles	Wood	Paper & Paper Products	Printing	Coke & Refined petroleum	Chemicals & Pharmaceutical	Rubber & Plastic	Non-metallic minerals	Basic Metals	Electronics & Electrical Engineering	Motor vehicles
1.Non-water sectors	438.07	104.54	1019.20	46.88	100.63	186.26	102.28	547.00	574.86	291.01	166.08	1691.601	932.71	706.70
2. Water sector	5.51	0.68	6.34	0.49	0.32	0.98	0.37	4.99	13.29	1.05	1.60	10.539	3.68	1.26
3. Water use (value)	34.09	3.15	19.48	0.48	1.56	1.08	0.29	0.84	10.84	0.70	1.65	6.277	3.33	6.30
4.Water payment adjustment	-28.58	-2.47	-13.14	0.01	-1.23	-0.10	0.08	4.15	2.44	0.35	-0.06	4.262	0.35	-5.04
5. Other primary inputs	961.53	225.03	2014.19	226.78	391.10	689.91	449.27	4583.14	2192.64	913.70	495.83	4847.322	3440.25	1746.81
6. Total inputs	1405.09	330.266	3039.73	274.15	492.06	877.15	551.93	5135.13	2780.78	1205.76	663.51	6549.461	4376.64	2454.77
7. Physical water use (millM3)	12.36	1.14	7.06	0.17	0.56	0.39	0.10	0.31	3.93	0.25	0.60	2.27	1.21	2.28

Table 1 Continued

	Other transport	Furniture	Electricity gas, waste & sewage	Water	Construction	Wholesale & Retail	Transportation	Accommodation	Finance & Insurance	Other business services	Public Adminis tration	Education	Health	Other services
1. Non-water sectors	535.79	192.01	2543.56	480.89	1690.98	1986.40	933.10	575.50	1154.37	1771.42	1434.40	538.05	2957.29	720.43
2. Water sector	2.70	0.21	2.86	0.32	6.41	4.55	1.54	10.21	1.09	4.167	12.89	6.51	6.46	3.23
3. Water use (value)	4.83	2.63	5.22	0.58	1.84	9.22	4.41	15.97	2.66	12.601	9.38	9.85	14.64	6.11
4. Water payment adjustment	-2.13	-2.42	-2.35	-0.26	4.57	-4.67	-2.86	-5.77	-1.57	-8.433	3.50	-3.34	-8.18	-2.88
5. Other primary inputs	1723.80	728.80	2734.05	216.6	3401.78	6590.29	2719.96	2039.37	2744.31	10776.20	4899.40	3107.50	5198.50	2908.28
6. Total inputs	2262.29	921.01	5280.48	697.82	5099.17	8581.27	3654.61	2625.09	3899.78	12551.80	6346.70	3652.10	8162.2	3631.94
7. Physical water use (millM3)	1.75	0.95	1.89	0.21	0.67	3.34	1.60	5.79	0.96	4.57	3.40	3.57	5.31	2.21

Table 1 Continued

	Total Intermediate Demand	Households	Tour 1-3	Tour 4+	Tour Intl	Tour Bus	Government	GFCF	Stock2007	Exports RUK	Exports ROW	Total Final Demand	Total Demand Products
1.Non-water sectors	24055.12	18731.33	217.37	964.26	296.33	217.03	13785.90	3003.90	498.60	25840.20	8828.40	72382.90	140219.10
2. Water sector	114.26	512.42	0.14	0.63	0.17	0.15	0.00	15.44	38.56	15.23	0.84	583.56	697.82
3. Water use (value)	190.01	436.66	0.14	0.63	0.17	0.15	0.00	15.44	38.56	15.23	0.84	507.81	697.82
4. Water payment adjustment	-75.76	75.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	75.76	0.00
5. Other primary inputs	273.40	17639.60	26.20	159.50	41.90	28.20	481.70	2413.10	189.30	5448.10	1382.20	27809.81	100776.20
6. Total inputs	-33.90	36883.4	243.70	1124.40	338.40	245.40	14267.60	5432.40	726.50	31303.50	10211.10	100776.20	198278.90
7. Physical water use (millM3)	68.87	158.27	0.05	0.23	0.06	0.05	0.00	5.59	13.98	5.52	0.31	184.05	252.92

Table 2. Water Use in Wales in 2007 in thousand Cubic Meters ($1000M^3$)

	Sector/Activity	$X_{ki}/q_{i,T}$	a_{ki}	$X_{ki}p/q_{i,T}$	$m_2^p = w_2\left[I - A\right]^{-1}$		$m_1^p = w_1\left[I - A\right]^{-1}$		$m_3^p = w_2\left[I - A^*\right]^{-1}$	
1	Agriculture, Forestry & Fishing	0.00879	0.00392	0.02426	9.791	13.461	1.681	5.732	9.806	13.526
2	Mining & Quarrying	0.00346	0.00206	0.00954	3.789	6.312	0.897	3.682	3.794	6.334
3	Food & Drink	0.00232	0.00209	0.00641	3.748	6.289	1.073	3.878	3.753	6.310
4	Clothing & Textile	0.00063	0.00179	0.00174	0.751	3.827	0.718	4.113	0.751	3.824
5	Wood	0.00115	0.00066	0.00316	1.682	3.984	0.366	2.907	1.685	3.993
6	Paper & Paper Products	0.00045	0.00112	0.00123	0.624	2.536	0.499	2.609	0.624	2.535
7	Printing	0.00019	0.00067	0.00052	0.297	3.492	0.307	3.835	0.297	3.490
8	Coke & Refined Petroleum	0.00006	0.00097	0.00016	0.127	1.081	0.395	1.448	0.126	1.078
9	Chemicals and Pharmaceuticals	0.00141	0.00478	0.00390	1.574	3.767	1.832	4.253	1.574	3.763
10	Rubber and plastic	0.00021	0.00087	0.00058	0.358	3.463	0.424	3.852	0.358	3.460
11	Non-Metallic Mineral	0.00090	0.00241	0.00249	1.120	4.009	0.998	4.187	1.120	4.007
12	Basic Metals	0.00035	0.00161	0.00096	0.507	2.973	0.698	3.420	0.507	2.970
13	Electronics & Electrical Engineering	0.00028	0.00084	0.00076	0.401	3.000	0.391	3.260	0.401	2.998
14	Motor Vehicles	0.00093	0.00051	0.00257	1.115	3.222	0.323	2.649	1.116	3.227
15	Other Transport	0.00077	0.00119	0.00213	0.925	3.405	0.531	3.270	0.925	3.406
16	Furniture	0.00104	0.00023	0.00286	1.238	3.780	0.153	2.958	1.240	3.787
17	Electricity, Gas, Waste & Sewage	0.00036	0.00054	0.00099	0.747	3.018	0.391	2.898	0.748	3.019
18	Water	0.00030	0.00046	0.00084	362.448	362.451	362.810	362.451	362.811	362.813
19	Construction	0.00013	0.00126	0.00036	0.323	3.668	0.635	4.328	0.322	3.663
20	Wholesale & Retail	0.00039	0.00053	0.00107	0.574	4.437	0.278	4.542	0.574	4.436
21	Transportation	0.00044	0.00042	0.00121	0.585	4.670	0.232	4.742	0.585	4.670
22	Accommodation	0.00221	0.00389	0.00608	2.661	6.737	1.552	6.052	2.663	6.743
23	Finance & Insurance	0.00025	0.00028	0.00068	0.419	3.738	0.193	3.857	0.419	3.737
24	Other Business Services	0.00036	0.00033	0.00100	0.439	2.900	0.172	2.888	0.440	2.900
25	Public Administration	0.00054	0.00203	0.00148	0.683	5.679	0.834	6.349	0.683	5.673
26	Education	0.00098	0.00178	0.00270	1.110	8.233	0.719	8.583	1.111	8.230
27	Health	0.00065	0.00079	0.00179	0.995	5.302	0.458	5.213	0.996	5.303
28	Other Services	0.00061	0.00089	0.00168	0.749	5.040	0.398	5.135	0.749	5.039

Table 4. Impact on Output Prices of the adjustment to full Leontief environmental IO accounts

		Percentage change in price multiplier relative to unadjusted price IO	
		Type I effects (household exogenous)	Type II effects (household endogenous)
		Adjusted	Adjusted
	Sector/Activity	Case 1	Case 1
1	Agriculture, Forestry & Fishing	2.239%	2.177%
2	Mining & Quarrying	0.799%	0.756%
3	Food & Drink	0.739%	0.696%
4	Clothing & Textiles	0.009%	-0.042%
5	Wood	0.363%	0.325%
6	Paper & Paper Products	0.035%	0.003%
7	Printing	-0.003%	-0.056%
8	Coke & Refined Petroleum	-0.074%	-0.090%
9	Chemicals & Pharmaceuticals	-0.071%	-0.108%
10	Rubber & Plastic	-0.018%	-0.070%
11	Non-Metallic Mineral	0.034%	-0.015%
12	Basic Metals	-0.053%	-0.094%
13	Electronics and Electrical Engineering	0.003%	-0.041%
14	Motor Vehicles	0.219%	0.183%
15	Other Transport	0.109%	0.067%
16	Furniture	0.300%	0.257%
17	Electricity,Gas.Waste & Sewage	0.098%	0.060%
18	Water	0.076%	0.035%
19	Construction	-0.086%	-0.142%
20	Wholesale & Retail	0.082%	0.017%
21	Transportation	0.097%	0.029%
22	Accommodation	0.306%	0.238%
23	Finance & insurance	0.063%	0.007%
24	Other business services	0.074%	0.033%
25	Public administration	-0.042%	-0.125%
26	Education	0.108%	-0.011%
27	Health	0.148%	0.076%
28	Other services	0.097%	0.025%

Table A1. Production Sectors/Activities Identified in the Wales Water IO Tables, 2007

	Sectors	SIC 2007 code	IO 2007 groups
1	Agriculture, forestry & fishing	A	1,2
2	Mining & quarrying	B	3,4
3	Food & drink	C10/11/12	5,6,7,8,9,10,11
4	Clothing & textiles	C13,14,15	12,13
5	Wood	C16	14
6	Paper & paper products	C17	15
7	Printing	C18	16
8	Coke & refined petroleum	C19	17
9	Chemicals & pharmaceutical	C20/C21	18,19,20
10	Rubber & plastic	C22	21,22
11	Non-metallic mineral	C23	23,24
12	Basic metals	C24/C25	25,26,27,28
13	Electronics & electrical engineering	C26/C27/C28/C32/C33	29-37,41
14	Motor Vehicles	C29	38
15	Other transport	C30	39
16	Furniture	C31	40
17	Electricity, Gas, Waste & Sewerage	D	42,43,44,45,46,47,48,87
18	Water	E	49
19	Construction	F	50
20	Wholesale & retail	G	51,52,53
21	Transportation	H	60-63
22	Accommodation	I	54-59
23	Finance & Insurance	K	67,68,69
24	Other business services	LMN	70,71,72,73-79
25	Public administration	O	80
26	Education	P	81
27	Health	Q	82
28	Other services	JRSTU	65,66,83-86, 88